Improved PSF-based EPI Distortion Correction in Human Imaging at 7 Tesla

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INTRODUCTION

The point spread function (PSF) mapping method can detect geometric distortions in EPI reliably [1-4]. However, challenges remain due to strong local susceptibility effects resulting in strong local image stretching and compression, especially for ultra high field (UHF) such as 7T. These effects lead to local broadening and distortions of the PSF peak itself, and it is often difficult to determine the shift value of the distorted PSF peak accurately. This problem can likely be attributed to the fact that the determination of shifts of the PSF is commonly performed in the undistorted (spin warp) coordinates. In order to overcome the aforementioned correction problems, we present a modified PSF mapping method which is processed in the distorted dimension instead of the undistorted dimension.

MATERIALS AND METHODS

PSF and EPI data were acquired at 7 Tesla. From the PSF data the shift map was calculated as described by Zaitsev et al. [3] with four modifications yielding our proposed method. Phase correction of the 3D PSF data is required to avoid the appearance of step-like patterns in the pixel shift maps. In the proposed method, not the GE image, as used in the original method, but the EPI image was used, which can be obtained by integration along the undistorted dimension. In order to determine the center of the PSF peak and thus the pixel shift map more accurately, the phase fitting method proposed by Ahn et al. has been applied [5]. An image mask needs to be created to limit the calculation to areas of sufficient signal inside the object. Therefore, the standard deviation (StdDev) image was used. However, in contrast to the previous methods [1-4], the image mask and the shift map were calculated from the 3D PSF data along the undistorted dimensions (Fig. 1). The final shift map is smoothed using a 2D three-pixel median filter after weighted linear extrapolation of the shift map to the areas outside of mask. For distortion correction this shift map is applied to the corresponding distorted EPI image by standard convolution in image space, and 1D 2nd order b-spline interpolation with 3 support points is used for high estimation accuracy with acceptable calculation times.

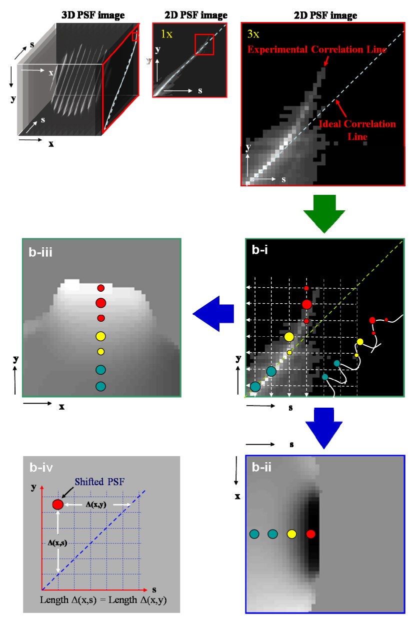

Fig. 1: PSF-map illustrating the detection of distortions along the distorted (y) and undistorted (s) dimensions.

RESULTS AND DISCUSSION

In human imaging, flow artifacts can strongly affect the distortion correction. These artifacts are caused by the multi-shot nature of the reference scan, leading to phase inconsistencies in case of pulsatile flow and thus falsely localized representations of flowing structures. Therefore, the 3D PSF data can contain strong flow artifacts in the artery and ventricle regions (Fig. 2). In this case, only the shift mapping procedure along the undistorted dimension can avoid these flows induced ghost artifacts in the shift map (see Fig. 2 and 3). The proposed modification allows determination of the local shift with significantly higher spatial accuracy due to the distribution across multiple voxels in case of local stretching (see Fig. 1 and 3). In compressed regions, spatial information has already been lost in the EPI acquisition process and cannot be recovered, even with higher accuracy mapping as potentially offered by mapping along the distorted dimension. However, intelligent combination of both shift map versions may further improve the correction and is subject of future studies.

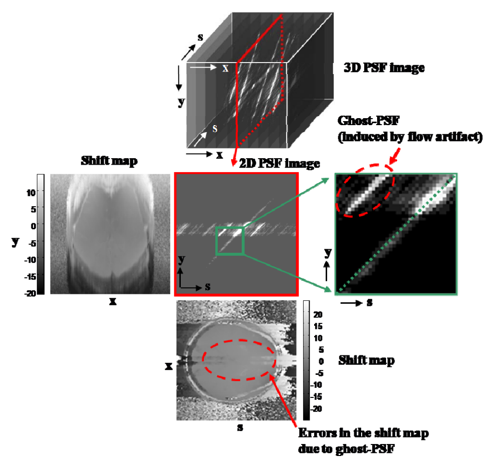

Fig. 2 The difference of PSF mapping along the undistorted dimension (s) and the distorted dimension (y) in an in-vivo human brain. For the PSF mapping technique along the distorted dimension (y) distortion as well as flow-induced ghost-PSF can be identified. However, with PSF mapping along the undistorted dimension (s), an artifact free distortion map is calculated.

CONCLUSION

This method allows measurement and correction of the geometric and intensity distortions in EPI with high accuracy and reduction of blurring. In addition, the proposed method effectively removs flow induced ghost artifacts in the shift map.

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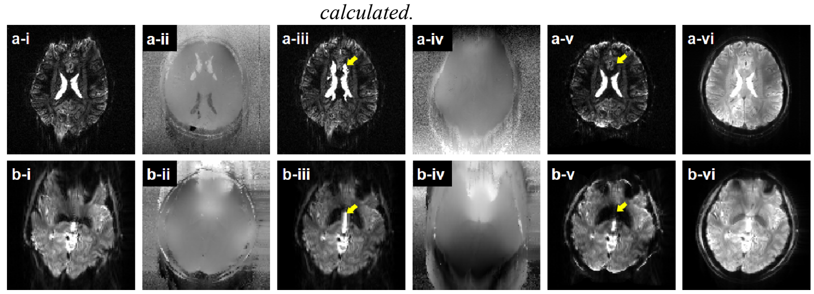

Fig. 3 The shift map error from the flow-induced ghost-PSF and the correction results for in-vivo human brain imaging. (a) and (b) show effects of the ventricles and arteries, respectively: (a-i) and (b-i) distorted EPI image, (a-ii) and (b-ii) raw shift map obtained by the original method, (a-iii) and (b-iii) correction results by the original method, (a-iv) and (b-iv) raw shift map calculated by the proposed method, (a-v) and (b-v) correction results by the proposed method, (a-vi) and (b-vi) undistorted reference image (GE-StdDev).